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INVESTIGATIONS OF THE ADMISSIBLE OXYGEN FLOW VELOCITY IN STEEL PIPES FROM A SAFETY POINT OF VIEW

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INVESTIGATIONS OF THE ADMISSIBLE OXYGEN FLOW VELOCITY IN STEEL PIPES FROM A SAFETY POINT OF VIEW*

W. Wegener

Operational Dangers and Safety Requirements /469**

The use of steel pipe in pipe systems for compressed oxygen has been subjected to certain safety requirements in Germany since the year 1942.*** It has only been modified slightly since that time. One of the important restrictions is the limitation of the flow velocity of oxygen to 8 meters/second. The reason for this restriction is that at higher velocities there is a danger of pipe fires. This occurs when scale and corrosion products separate when moist oxygen is being transported. These products are then carried along by the flow and can start to glow because of friction at the pipe walls. The existence of this danger has /470
been verified in a certain sense. When new pipelines which are somewhat contaminated are cleaned by a high-pressure flow, one can observe fire phenomena at the two ends. The oxygen flow velocities which occur are then considerably higher than those usually used in the operation of the system. On the other hand,

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**Numbers in the margin indicate pagination of the original foreign text.

***Joint Bulletin of the Reichs Business Ministry and Reichs Labor Ministry of November 28, 1942, as well as directives for the use of steel pipes in pipe systems (distribution networks for compressed oxygen). Reichsarbeitsbl. (1943) Nr. 1, P. III, 1, u. Bundesarbeitsbl. (1955) Nr. 12, P. 481/84.

the oxygen pressure is relatively low.

The operational dangers which did occur at the time were tested by experiments. However, the experimental results were not published. Therefore today we can no longer determine what the exact conditions were for which flashes occurred in pipes. Other investigations showed that the oxygen lines installed up to the year 1942 were made of unalloyed steel almost without exception. Also we found that the systems were operated at flow velocities below 8 meters/second. Apparently the oxygen fluxes corresponded to the operational requirements. This could have been the reason why the highest permissible velocity was specified at 8 meters/second. According to present technical requirements, this limiting value is too low.

The directives for Germany were in part taken over by other countries. For example, in the United States and Great Britain, other recommendations have been published. In these cases, they were usually in the form of plant specifications or they were specified by insurance companies. They are different from the German specifications because they allow higher flow velocities which are specified independent of the pressure.

Good results have been obtained with flow velocities over 8 meters/second. For this reason and because oxygen is being used in metallurgical installations to an ever increasing degree, the Association of German Iron Miners and the Mining and Rolling Mill Associations decided many years ago to again test the safety aspects for oxygen steel pipe systems. The purpose was to reduce the restrictions. A research contract was awarded to the German Institute for Material Testing (BAM) after a joint conference with the Ministries for Labor and Social Order, the BAM and other occupational associations and operators of air-separation plants.

Experiment Planning

The experiment planning was structured into three phases.

1. A suitable test set-up had to be developed for experiments under laboratory conditions. This installation was operated at differing flow velocities. Solids were introduced into the oxygen stream and their influences in straight and curved pipes was observed. The experimental set-up had to be designed so that it could be transferred to larger scales with as little change as possible.

2. Subsequent to this, a large test section should be operated, in which experiments made with the installation mentioned in Paragraph 1 could be made.

3. Finally a continuous test section is to be installed, in which oxygen, having the conventional purity, i.e., without any solid additives, was to be operated over a time period of several weeks at a high velocity.

The experiments carried out under laboratory conditions were performed in the open air ground installation of the German Ministry for Material Testing in Berlin-Dahlem. They were concluded approximately two years ago. The experimental set-up and the essential results were reported in [1]. This is why we will now report on the second and third phases of the experiments.

The test sections were built at the Duisburg-Ruhrort factory of the Phoenix-Rheinrohr AG.

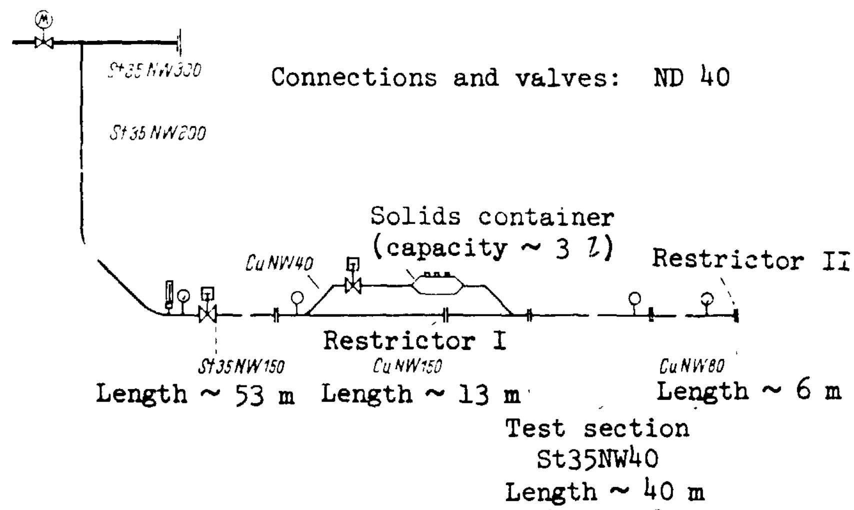


Figure 1. Diagram of the experimental set-up.

Experimental Set-Up

From an approximately 15-meter high NW 300 (nominal width 300 mm) oxygen pipe there is a NW 200 bend which drops down perpendicular to it. It runs into a vertical NW 150 pipe through a sleeve valve. After 53 m, the steel pipe is extended by means of a 13 m long copper tube pipe having the same dimensions. From this main line there is a bypass line, which can be closed off by means of a sleeve valve. It contains a container for introduced solids (Figure 2). Just before the connection flanges for the test section, there is a connection between the bypass line and the main line. The adjacent test section ends with a 6-m long safety section, which has exchangeable restrictors in it. The restrictor diameter determines the amount of oxygen flowing per unit of time and therefore also determines the flow velocity in the

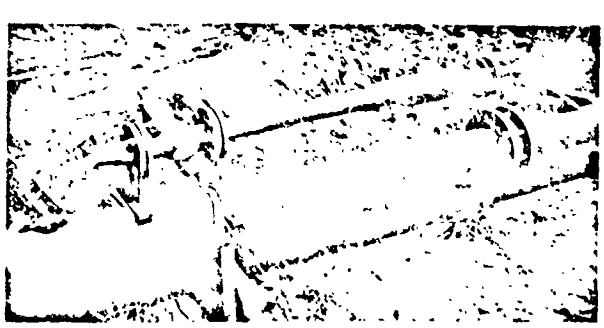


Figure 2. Bypass pipes with container for collection of solids.

test section. The safety line and the restrictors are made of copper. If steel were used, the solids carried along by the oxygen flow could trigger an undesirable fire in the pipe when they impact the restrictor vertically. /471

The oxygen flows into the free atmosphere. Because of the considerable noise levels, it later on became necessary to install a sound absorber at the pipe end. It also seemed appropriate to install the restrictors in an eccentric manner along the lower parts of the tube end, so that the introduced foreign particles could not accumulate there.

There is an additional restrictor in the main line between the tap and reentry point of the bypass line. Because of the restricted tube cross section at this point, part of the oxygen flows through the bypass line and carries along the materials introduced into the container. Manometers are installed ahead of the test section as well as at its end. These measure the pressure decrease in the line. All the lines and the valves are designed for ND 40 (nominal pressure 40 atmospheres gauge pressure). The valves are operated from a secured panel with a pneumatic system.

Forty-meter long straight steel pipes having nominal dimensions of 40, 50, 65 and 80 were available for the test section. However, as we will show later on, only the NW 40 line could be used. During the experiments in the middle of the test section, i.e., that is about 20 meters from the beginning, either two 5s bends (arc radius = 5 x tube radius) or an expansion arc with four 3s or 5 D bends (arc radius = 5 x pipe radius) were welded in.

Determination of the Flow Velocity

A uniform flow velocity, which was not known at first, was adjusted by means of the restrictors (Figure 1), which were installed at the ends of the safety line. This meant that repeatable experimental conditions were produced. The oxygen flux could not be determined with measurement restrictors, because there was a danger that the writing instruments would be damaged because of the pressure shocks in the line which occur when the slide is open and closed before and after each experiment. Since the aperture ratio of the measurement restrictor should correspond to the expected flux, it would have been necessary to exchange it with a considerable expenditure in time when other velocities were tested.

Another possibility for calculating the oxygen flux was then considered. This is based on the fact that compressed gases flow into the atmosphere at the speed of sound, as long as the pressure ratio is above the critical pressure ratio. The amount of outlet flow is primarily determined by the pressure and temperature of the gas ahead of the restrictor as well as the restrictor cross section. The discharge ratio α must be introduced as a correction factor. It considers the jet constriction due to sharp edges and similar effects. Therefore it essentially depends on the geometric shape of the restrictor. Because of the unknown discharge ratios in the restrictors, the calculated discharge amounts were uncertain.

Finally another method was used. It led to exact values. The NW 300 oxygen line mentioned and used in the experimental arrangement could be closed off over a distance of about 360 m by means of a slide. This closed off part of the tube including the main line ahead of the test section forms a "container" having a volume V_B of about 27 m^3. After the slide in the main line is opened, the oxygen flows through the test section and through the final restrictor to the outside air. The line pressure decreases from about 28 atmospheres operational pressure to about 10 atmospheres depending on the cross section of the final restrictor and during a time interval of about 5 to 20 minutes. If the recorded pressure p values are plotted as a function of time t in the form lg p = f(t), we obtain a straight line. The inclination of this line is proportional to the flow velocity at the beginning of the test section. The somewhat simplified derivation is as follows (notations see Table 1):

TABLE 1

NOTATIONS USED

F	=	cross section of the test section in m^2
V_B	=	volume of the pipe segment which can be blocked ahead of the test section in m^3
p_0	=	normal pressure (= 1.033 at)
T_0	=	normal temperature (= 273° K = 0° C)
V_0	=	gas flow in Nm^3/sec reduced to normal conditions (p_0, T_0)
p	=	gas pressure in at
T	=	absolute gas temperature in °K
w	=	gas velocity in meters/second
t	=	time in seconds
1, 2, 3	=	subscripts characterizing the experimental conditions at the following points: 1 — at the beginning of the test section; 2 — at the end of the test section; 3 — in front of the final restrictor
p', t', T'	=	for unsteady flow [$(dp/dt) \neq 0$], p and p' are the gas pressures at the times t and t', respectively, in the range of constant temperature T'.

The gas volume flowing through the NW 300 line per unit of time and recalculated per normal conditions is specified by the equation

$$V_0 = -V_B \cdot \frac{1}{p_0} \cdot \frac{T_0}{T_1} \cdot \frac{dp_1}{dt} \tag{1}$$

The same pressure and the same temperature exist at the beginning of the test section. The equation which specifies the gas volume, also recalculated for normal conditions, flowing through the cross section F per unit of time at the velocity w_1 — if the pressure change dp is ignored — is

$$V_0 = F \cdot w_1 \cdot \frac{p_1}{p_0} \cdot \frac{T_0}{T_1}. \tag{2}$$

Since the gas fluxes specified by Equations (1) and (2) must be the same, the differential quotient has the value

$$\frac{dp_1}{dt} = -\frac{F}{V_B} \cdot w_1 \cdot p_1. \tag{3}$$

After transforming the above, we obtain the following equation which must be integrated

$$\int_{p_1'}^{p_1} \frac{dp_1}{p_1} = -\frac{F}{V_B} \cdot w_1 \cdot \int_{t'}^{t} dt \tag{4}$$

and after carrying out the integration we find

$$\ln p_1 - \ln p_1' = \frac{F}{V_B} \cdot w_1 \cdot (t' - t). \tag{5}$$

Using base ten logarithms, we finally obtain the following equation for the flow velocity at the beginning of the test section

$$w_1 = 2{,}3026 \cdot \frac{V_B}{F} \cdot \frac{\lg p_1 - \lg p_1'}{t' - t}. \tag{6}$$

In the determination of w_1 it is necessary to consider the /472
fact that the oxygen cools off ($T_1 \rightarrow T'_1$) during expansion in the NW 300 line. It was found that for a pressure drop from 28 atmospheres to about 20 atmospheres the temperature dropped from between 8 to 10 degrees C below the outside temperature. However, because of the increase in heat transfer, from the atmosphere, it remained constant along the line. The function lg p = f(t) is therefore only linear in the range of the final temperature T'_1. Figure 3 shows such a curve.

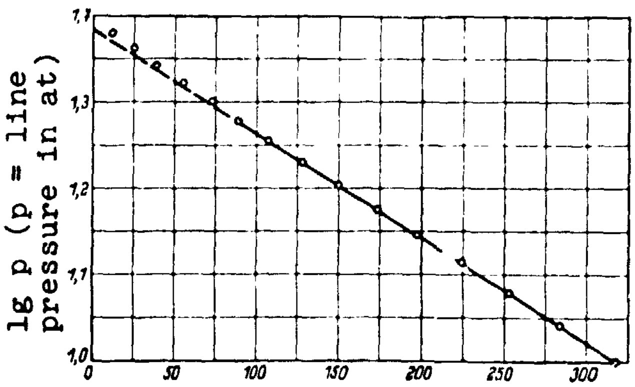


Figure 3. Pressure decrease in the pipe NW 300.

The velocity w_1 calculated according to Equation (6), which is only valid for T'_1, can be corrected for any other temperature T_1 by multiplying it with $\sqrt{T_1/T'_1}$. This correction factor is found from the temperature dependence of the velocity of sound which exists at the final constrictor. It is not important whether the gas temperatures T_3 or T'_3 (ahead of the final restrictor) agree with the gas temperature T_1 or T'_1 (at the beginning of the test section), respectively, This is because the value of the quotient T_n/T'_n remains almost unchanged. This then results in the final relationship for the flow velocity at the beginning of the test section

$$w_1 = 2{,}3026 \cdot \frac{V_B}{F} \cdot \frac{\lg p_1 - \lg p'_1}{t' - t} \cdot \sqrt{\frac{T_1}{T'_1}} \qquad (7)$$

The pressure p_2 at the end of the test section can be calculated according to the flow velocity which exists there

$$w_2 = w_1 \cdot \frac{p_1}{p_2} \tag{8}$$

w_1 to be substituted is taken from Equation (7). No temperature correction is necessary because there were no measurable differences between T_1 and T_2.

The values of w_1 and w_2 determined in this way for various restrictor cross sections have a maximum possible error of ±3%. It is important to realize that for steady flow, the velocity found is independent of the absolute pressure in the main line. This means that fluctuations in the average 28 atmospheres operational pressure could be ignored.

Experimental Procedure

Before each test series we determined the flow velocity w_1 and measured the pressures p_1 and p_2 at the beginning and end of the test section. It was especially important to make sure that there were no differences when the bypass line was opened or closed. Otherwise the cross section of the restrictor in the main line had to be enlarged. The measurements after each test series gave values within the experimental error bounds.

During the test series, the slide in the NW 300 line remained open. Thus the same pressure prevailed at all times (27 to 29 atmospheres, corresponding to the operational pressure).

The container in the bypass line was filled with 1 to 2 kg of solids while the main line was not under pressure. It was then again hermetically closed. After the slide was opened in the main line, we first had to wait until there were stationary flow conditions. Then the slide in the bypass line, which had been closed up to that time, was operated and the solids were introduced from the container into the test section. Depending on the material, the container was emptied after 0.5 to 1 minutes. As soon as there was only pure oxygen in the test section, the experiment could be terminated.

We used roll scale, welding cinders and rust as solids. These are materials which can be introduced into the lines by modification, operation or displacement of the systems. In addition, we also used sand. For example, sand is used for sand blasting storage containers. We used flue dust as a comparison material because of its high iron oxide content. We also used coke, stone coal, and sand and iron powder mixtures, which are more or less combustible materials. The solids were sometimes in powder form or in granular form. The grain sizes were as high as 5 mm. The dry oxygen used had a purity of about 99.6%.

The first experiments were carried out in a straight pipe segment at a flow velocity of 30 meters/second at the beginning and 33 meters/second at the end of the test section. According to results of earlier laboratory experiments [1], these conditions were still not dangerous for the lines. Later on we increased the initial velocity up to 53 meters/second when various lines, both curved and straight, were installed. The final velocity calculated from a pressure loss of 38% amounts to 85 meters/second. It was not possible to obtain steady velocities because of the capacity of the air-separation installation. This is why we were not able to use lines larger than NW 40 as initially planned. In order to give a fair representation of the operational conditions, we primarily carried out experiments with curved lines. In contrast to this, it was only necessary to carry out a small number of experiments with straight lines. This was because in lines having curved segments, there was a 20-meter long straight pipe segment after them.

Experimental Results

Table 2 shows the results obtained with various materials for various oxygen flow velocities for the straight test section. Table 3 shows the same thing for the lines with curved segments. It is not necessary to further classify them according to radii of the pipe bends, because we were not able to detect differences in the experimental results.

The final restrictors used to limit the discharged amounts of oxygen had diameters of 12, 13, 15, 20, 26, and 32 mm. Accordingly, there were stepped flow velocities in the test section. As the number of experiments was increased, the restrictor cross section gradually increased because of erosion, so that the flow velocity also increased. The oxygen temperature /473
which depends on the outside temperature also had a small influence on the flow velocity. In addition, the oxygen pressure fluctuated according to operational conditions. Nevertheless, all experimental conditions remained within small limits.

Rust, Flue Dust, Sand

The solids rust, flue dust and sand were found to be safe. We were not able to find glowing particles at the end of pipes or flashes in the pipes themselves in either straight lines or lines having several bends. Flow velocity values up to 53 meters/second and oxygen pressures up to 28 atmospheres prevailed at the beginning, and the maximum values at the end of the test section were 85 meters/second and 17 atmospheres. We could only observe dense dust clouds.

TABLE 2

EXPERIMENTAL CONDITIONS AND RESULTS

FOR A STRAIGHT TEST SECTION

Added solid	Flow velocity w and pressure p of oxygen at the beginning (subscript 1) and at the end of the test section (subscript 2)				Number of experiments and results*
	w_1 in m/s	p_1 in ata	w_2 in m/s	p_2 in ata	
Sand	18 33 51	28 26 27	19 37 84	27 23 16	1 – 2 – 3 –
Rust	33 44 51	25 28 27	37 57 84	22 22 16	2 – 2 – 2 –
Flue dust (deposited)	29 — 33 44 51	25 28 27	33 — 37 57 84	22 22 16	3 – 2 – 2 –
Roll scale	33 44 51	25 28 27	37 57 84	22 22 16	1 – 2 – 2 –
Welding cinders	33 44 51	25 29 27	37 57 84	22 23 16	1 – 2 + 2 –
Coke	29 — 33 44 51	25 29 27	33 — 37 57 84	22 23 16	2 –, 1 + 2 + 3 +
Stone coal	11 13 18	29 22 — 29 20 — 29	11 13 19	29 22 — 29 19 — 28	1 – 3 –, 1 + 4

*+ = sparks observed; – = sparks not observed

Roll Scale

The same is true for roll scale in the case of straight lines only. In curved lines, glowing particles emerged from the pipe ends at an initial velocity of 28 meters/second. In the case of an increased initial velocity of 52 meters/second in one

TABLE 3

EXPERIMENTAL CONDITIONS AND RESULTS

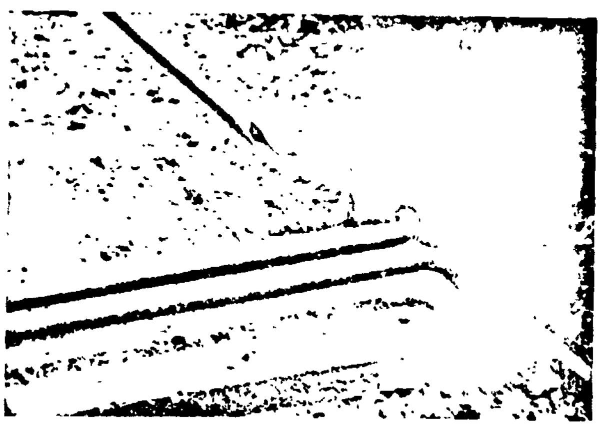
FOR A CURVED TEST SECTION

Added solid	Flow velocity w and pressure p of oxygen at the beginning (subscript 1) and at the end of the test section (subscript 2)				Number of experiments and results*
	w_1 in m/s	p_1 in ata	w_2 in m/s	p_2 in ata	
Sand	30 — 32 43 — 44 52	28 — 29 26 — 28 28 — 29	33 — 36 55 — 57 82	25 — 26 21 — 22 18	4 – 3 – 12 –
Rust	30 — 32 43 — 44 52 — 53	28 — 29 26 — 28 27 — 29	33 — 36 55 — 57 82 — 85	25 — 26 21 — 22 17 — 18	4 – 3 – 18 –
Flue dust (deposited)	30 — 32 43 — 44 52 — 53	28 — 29 26 — 28 28 — 29	33 — 36 55 — 57 82 — 85	25 — 26 21 — 22 17 — 18	4 – 3 – 16 –
Roll scale	28 — 32 42 — 44 52 52	28 — 29 27 — 29 29 29	30 — 36 55 — 57 82 82	25 — 26 21 — 22 18 18	11 –, 2 + 5 –, 9 + 3 –, 4 +
Welding cinders	13 17 28 42 — 44 50 — 53	29 29 29 27 — 29 28 — 29	13 18 31 55 — 57 82 — 85	29 28 26 21 — 22 17 — 18	Fire after the first bend 2 – 2 + 6 –, 4 + 1 –, 5 + 2 –, 13 +
Submerged arc welding cinders	42 — 44 50 — 52	27 — 29 27 — 29	55 — 57 82 — 83	21 — 22 17 — 18	3 –, 3 + 9 –, 1 +
Coke	17 30 — 32 42 — 44 52 — 53 53	29 28 — 29 27 — 29 27 — 28 29	18 33 — 36 55 — 57 82 — 85 85	28 25 — 26 21 — 22 17 — 18 18	2 –, 1 + 5 + 18 + 13 +
Stone coal	13 13 32	29 29 29	13 13 36	29 29 26	Fire after the fifth bend 2 – Fire at many points Fire after second bend
Mixture of 20% iron dust and 80% sand	13 28 28 42	29 29 29 29	13 31 31 56	29 26 26 22	2 + 1 –, 2 + Fire after the third bend Fire after third bend

*+ = sparks observed; – = sparks not observed.

case the pipe line sparked. The fire occurred just behind the first bend of the expansion arc (Figure 4a) consisting of four 3s bends. This divided the test section into two parts. The oxygen emerged at a very high velocity from the segment ahead of the fire point. It blew away the resulting liquid iron oxide slag. As other investigations have shown, the presence of this slag is required in order for the burning of the steel to progress [2]. Consequently the fire in this section subsided immediately after the line was broken. The test section segment downstream of the fire location w s continuously bathed by the expelled oxygen. At the same time, the glowing slag was blown into the line. This is why the fire continued until the oxygen stream was cut off by closing the slide in the main line.

(a) Fire caused by roll scale after the first bend.



(b) Fire caused by coke behind the fourth bend.

Figure 4. Fire in the test section.

Welding Cinders

Some welding cinder particles began to glow in the straight line at initial velocities of 44 meters/second. In curved lines, some sparks occurred at 17 meters/second. However, we were not able to trigger a fire in the pipe for initial velocities up to 53 meters/second. In curved tubes and with sillicate slag from submerged arc welding, which contained almost no free iron, we were able to observe individual weak sparks for initial velocities of 44 meters/second.

Coke, Stone Coal, Iron Powder

As expected, much more dangerous conditions prevailed when coke, stone coal and iron powder were used than before. In the straight tube, we were able to observe glowing of the coke particles at initial velocities of 30 meters/second. In curved pipes this occurred beginning with 17 meters/second. At an initial velocity of 53 meters/second, the pipe burned out behind the fourth 3s bend of the expansion arc (see Figure 4b). With stone /474
coal , during the first experiment with the line having two 5s bends, a fire occurred behind the second bend. The flow velocity was approximately 34 meters/second. Further experiments showed that stone coal ignites in straight as well as in curved pipes at velocities above about 13 meters/second. In one case, ignition occurred very close to the entrance of the bypass line into the test section. Apparently a dust explosion originated at this point, because the test section as well as the bypass line with the solids container was broken into many parts. In addition, various burned points were found in the destroyed pipe ahead of the expansion arc. When an 80% sand and 20% iron powder (flame powder) was used, some sparks were observed at flow velocities of 13 meters/second. At 28 meters/second initial velocity, the line behind the third 3s end of the expansion arc burned off. In the experiments carried out under laboratory conditions [1] with iron powder, ignitions were obtained only above 43 meters/second.

The course of the line fire in the experiment with roll scale was similar to what was observed with coke, stone coal or iron powder. We also found here that the fire does not advance in the direction opposite to the oxygen flow direction. In one experiment, we were only able to observe a fire phenomenon which lasted a short time. In this case the recoil produced by rupture of the line which was transferred perpendicular to the main flow direction because of the installed bend tore the line out of the foundation and bent it greatly. The emerging oxygen was no longer able to reach the part of the line downstream of the fire. After the oxygen remaining in this line segment had been reduced to normal pressure by expansion into the atmosphere, the fire could no longer be maintained because of insufficient oxygen supply.

Continuous Run Test Section

In order to install a continuous run test section, which was to have been operated at flow velocities of more than 8 meters/second, an oxygen line installed in the factory was bridged by means of a low cross section bypass line. The bypass line consisted of two 20-meter long ND 40 and NW 50 steel pipes. At first, the reversal point was connected by a large copper arc. The oxygen flux was increased over two days until a velocity of w_1 = 29 meters/second was reached at the beginning of the line at a pressure of p_1 = 36 atmospheres. The corresponding conditions at the end of the line were p_2 = 33 atmospheres and w_2 = 32 meters/second. After a time period of 36 days, the copper arc was replaced by a connection piece made of steel pipe containing two 3s bends. This bypass line, which was made entirely of steel, remained in continuous operation for another 28 days under the stated conditions. No complaints were recorded over the time span which extended over more than two months. No changes could be observed inside the line compared with the earlier state.

Consequences for the Test Results

In the experiments described above, we did not determine after what path length the velocity of the introduced solids reached a certain constant fraction of the flow velocity of the oxygen. According to other investigation results,* we may assume that there is a uniform velocity ratio after only a few meters. The question of the eigen velocity of the solids remains unanswered as well as their dependence on certain parameters such as density, drain size and shape of the particles, as well as pressure and velocity of the oxygen. These questions were not investigated further because we believed that even if the kinetic energy of the particles were known, for example, the production of sparks in the lines could not be adequately explained. In addition, the kinetic energy of identical particles would only have resulted in a statistical average value. This is because in all test conditions used, there were turbulent flow conditions in which the materials moved not only parallel but also perpendicular to the tube axis. In addition, we must consider the fact that it would be difficult to experimentally verify theoretical models because processes which occur inside the pipes could not be directly observed. For this reason it is not possible even for experiments with the straight line to state where and at what velocity and pressure the particles start to glow because of friction or where they start to burn. We can even assume that some sparks are produced by impact of the particles along the restrictors at the tube ends. The fact that there are significantly more sparks in curved lines even at low velocities leads us to believe that they are produced in the bends. In addition the observed line fires always begin just behind the bends. We were clearly able to show /475
that glowing particles will only occur in the lines, or line fires

*Private communication of the British Oxygen Company, London.

will only occur when the velocity carries along combustible solids at a sufficiently high velocity. Among these materials we have roll scale and welding slag, because they contain some amounts of free metal. Non-combustible materials such as rust and sand only lead to mechanical damage to the pipes at the velocities used here.

We could imagine that adding stone coal, coke and iron powder would considerably intensify the experimental conditions. If we consider the fact that often easily combustible materials can be contained in newly laid lines, then the experimental results are important for two reasons. First of all, they show how necessary it is to carefully remove all foreign material by pressure cleaning before the lines are used. They also show that it is dangerous to use oxygen for this purpose. This is why it is best to blow out the pipes using inert gases with no oil or with air containing no oil. On the other hand, there is no reason for alarm if combustible materials are sucked into the line after setting it into operation. There is the possibility that seal particles will enter the gas stream, but only experience can show whether this danger really exists. In any case, we did not obtain any information on such a danger during the experiments with the continuous test section.

It is not absolutely certain that all scale in pipes can be removed by staining before they are laid. It is also not certain whether welding slag can be removed by blowing the pipes out after they are laid. These materials can separate from the pipe wall even after the line has been set into operation. However, there is immediate danger to the lines only at high velocities, which will probably not be used during operation because of the considerable pressure losses.

We do not have any reservations in using flow velocities greater than 8 meters/second in steel pipelines for pressure stages up to ND 40. If an upper value were specified, it would be easy to consider the safety aspects because of the economical limitations.

Danger to the Valves

Valves are required components of pipeline networks. In general they contain combustible seals which of necessity will be in contact with the oxygen stream. Such seals can start to burn much more easily than the metallic components. Therefore there is the danger that the sparks which can be produced under the given conditions will cause them to ignite. Not only the energy determines this, but also the duration over which they are effective. The questions related to this must be investigated in separate experiments.

In addition to danger to the seals by glowing particles, there is another danger for the valves. At pressure ratios of about 1.9 and up, flow velocities can occur which come close to the speed of sound. Under these conditions, thermodynamic effects can occur which will lead to a division of the gas stream into hot and cold partial streams if the valve has an unfavorable fluid-dynamic shape. These processes were already described a few years ago [3]. They must be given special attention because of numerous cases of damage caused by oxygen slides.

As long as no information and experience is available on the question of how an increased oxygen flow velocity in the lines will affect the operational safety of the valves, we must introduce appropriate measures in order to avoid accidents caused by valve fires.

In oxygen networks which are operated at flow velocities above 8 meters/second, new installations should only have valves in which the housings are made of special brass or other copper alloys. Pipe bends ahead of these valves should be avoided.

In existing lines, the installed valves with steel housings should be replaced by housings made of copper alloy if this is not too difficult. They can also be converted to remote control or at least have a fireproof covering so the operating personnel will be protected.

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Summary

By means of experimental investigations we wanted to clarify whether the oxygen flow velocity limit of 8 meters/second in steel pipes according to safety regulations could be increased without the danger of pipe fires. We were able to determine the conditions required to produce pipe fires by an appropriately designed test section in which the usual operational conditions were simulated and sometimes exceeded by introducing impurities such as rust, sand, welding slag, roll scale, etc., into the line. According to the experimental results, there is a danger

to the lines by the usual expected impurities only at high velocities which are usually not used in operational installations for reasons of economy (large pressure decrease). On the other hand, valves are exposed to more danger. Therefore special requirements must be placed on the design, selection of material and method of operation.

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16. Abstract
Investigations concerning maximum permissible safe flow rate for condensed oxygen in steel pipelines; it was found that solid dirt particles, such as rust, roll scale, etc., in steel pipe will not ignite as long as practical flow rates: i.e., those not causing significant pressure drop, are maintained; for various reasons, which require further study, fixtures, such as valves, constitute danger at flow rates above 8 meters/second; this can be prevented by use of copper alloy fixtures.

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